Low Cost Methods for Finding Tight Gas, Gas Shales and Coalbed Methane

by
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Abstract

Finding highly productive "sweet spots" in otherwise low permeability sand, shale and coal reservoirs involves delineating areas where natural fractures and gas charged, quality pay coexist. While there is general agreement that finding intense, open sets of natural fractures is essential, accomplishing this <u>ahead of drilling</u> has proven to be a major technical challenge. This paper discusses one approach undertaken by Advanced Resources to address this challange.

<u>Basic Technology</u>. To advance the state of the art in natural fracture detection and prediction technology, a field-based R&D project was undertaken by Advanced Resources International (ARI) and Barrett Resources for DOE/FETC's Low-Permeability Natural Gas Program.

The project originated at Rulison Field, Piceance Basin, Colorado and was subsequently applied to neighboring Mamm Creek Field. An integrated geological and geophysical approach proved to be successful in delineating areas with intense, open natural fractures in the tight, massively stacked Mesaverde (Williams Fork) lenticular sands:

- The starting point was a thorough examination of the structure and geology of the basin and the prospect area.

- Second, regional reconnaissance using Landsat Thematic Mapper (TM) and side-looking airborne radar (SLAR) data was used to identify fault-related geomorphic linears.

- Next, the basin was high-graded using data from a high-resolution aeromagnetic survey to identify regional prospects and trends related to basement faults.

Following the regional analysis, a 3-D, P-wave, multi-azimuth seismic survey was shot in the Rulison Field. The results of the 3-D survey were integrated with available 2-D seismic lines to map the nature, orientation and displacement of the thrust-related faults in the Williams Fork Formation. This data served as input to ARI's Geomechanical Model, FSD (Fault Stressed Domains), that was used to delineate areas ("envelopes") with fault related natural fracture clusters that provide enhanced permeability, essential for highly productive gas wells.

<u>Field Tests</u>. Two areas of the Rulison Field were selected for calibrating and testing the natural fracture mapping methodology and geomechanical model, North Rulison (the site of the 3-D survey) and South Rulison (a lightly drilled step-out area).

After calibrating the natural fracture detection technology in the North Rulison Test Area, the “before-drilling” field test of the technology was performed at South Rulison. At the time of the test, only a small number of mostly older wells had been drilled in the 20 section South Rulison field area.

<u>Results</u>. The well performance at South Rulison, for the wells drilled inside and outside the geomechanical model projected naturally fractured envelope, is tabulated and discussed below:

- The 12 wells drilled inside the naturally fractured envelope have EURs of 3.4 Bcf/well, three times better than the 1 Bcf/well average for the 23 wells drilled outside the envelope.

- The average net pay for the inside and outside the envelope wells is essentially the same, confirming that natural fractures provide the control on well performance.

Results of South Rulison Natural Fracture Detection Technology Test

	Wells Inside Naturally Fractured Envelope	**Wells Outside Naturally Fractured Envelope**
No. Wells	12	23
Average EUR/Well	3.4 Bcf	1.0 Bcf
Average Permeability (md)	17	6
Average Net Pay (ft)	266	224

Similarly, positive results were achieved at the Mamm Creek Field test site in the Piceance Basin.

Recently, the methodology was applied to Table Rock Field prior to the drilling of UPR’s Rock Island Unit #4-H horizontal Frontier Formation well in the Greater Green River Basin. The purpose of testing the geomechanical-based natural fractured technology was to confirm that a favorable natural fracture setting existed in the area and at the specific well site. Initial tests indicate that the Rock Island Unit #4-H well is capable of producing 12 to 20 MMcfd.

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Discussion Outline

1. **Importance of Tight Gas, Gas Shales and Coalbed Methane**

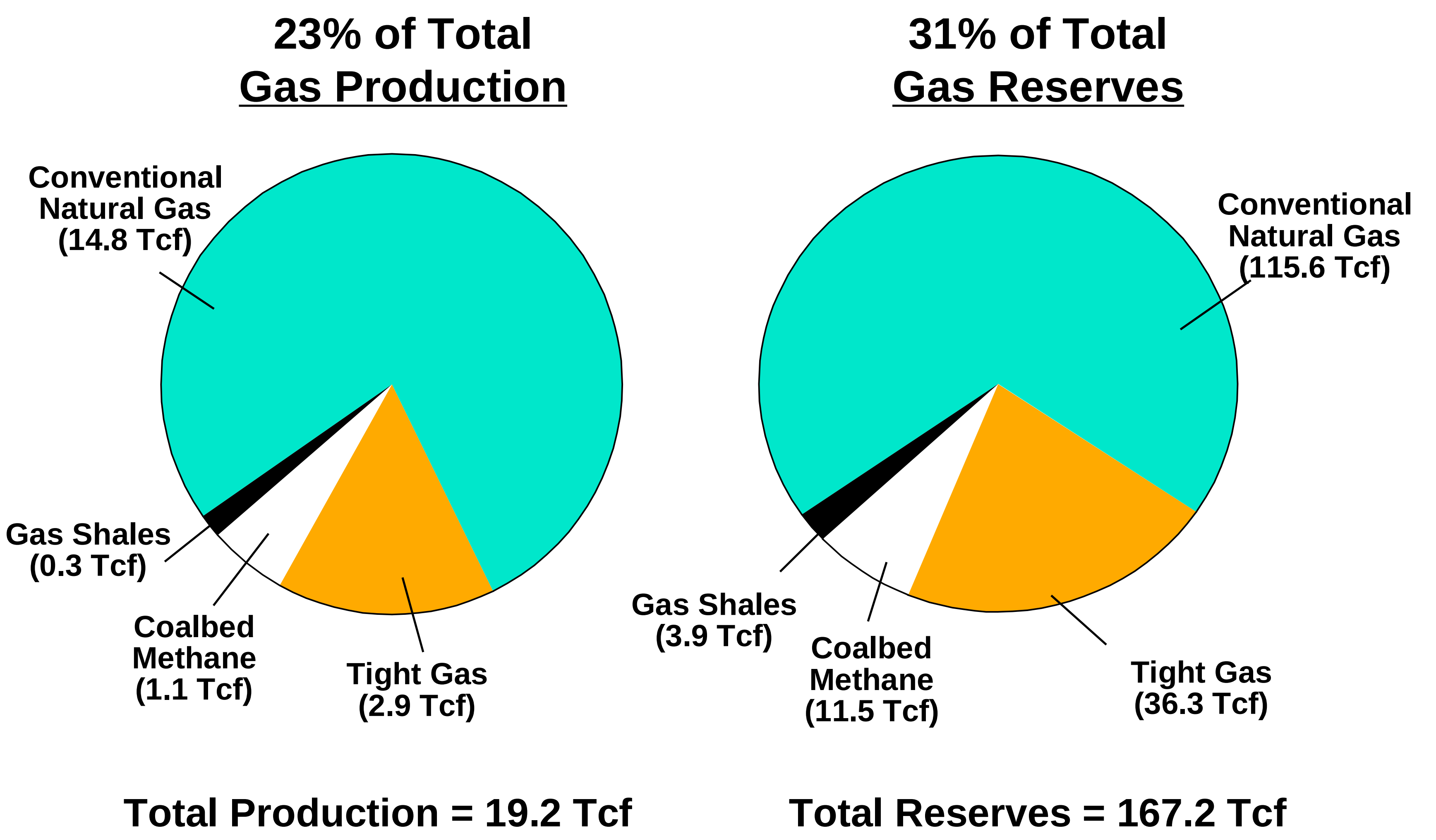
2. **The Exploration Challenge: Favorable Natural Fracture Settings**

3. **Successful Case Studies**
   - ***Southern Piceance Basin (Rulison)***
   - ***Eastern Green River Basin (Table Rock)***

Importance of Tight Gas, Gas Shales and Coalbed Methane

- **Tight Gas, Gas Shales and Coalbed Methane are fastest growing part of gas supply:**
  - ***23% of gas production***
  - ***31% of gas reserves***
- **Seven of top eleven natural gas fields produce "unconventional gas".**
- **Largest undeveloped portion of natural gas resource base.**

Tight Gas, Gas Shales and Coalbed Methane Are Already Essential Components of U.S. Natural Gas Supply



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U.S. Natural Gas Fields Producing Tight Gas, Gas Shales and Coalbed Methane

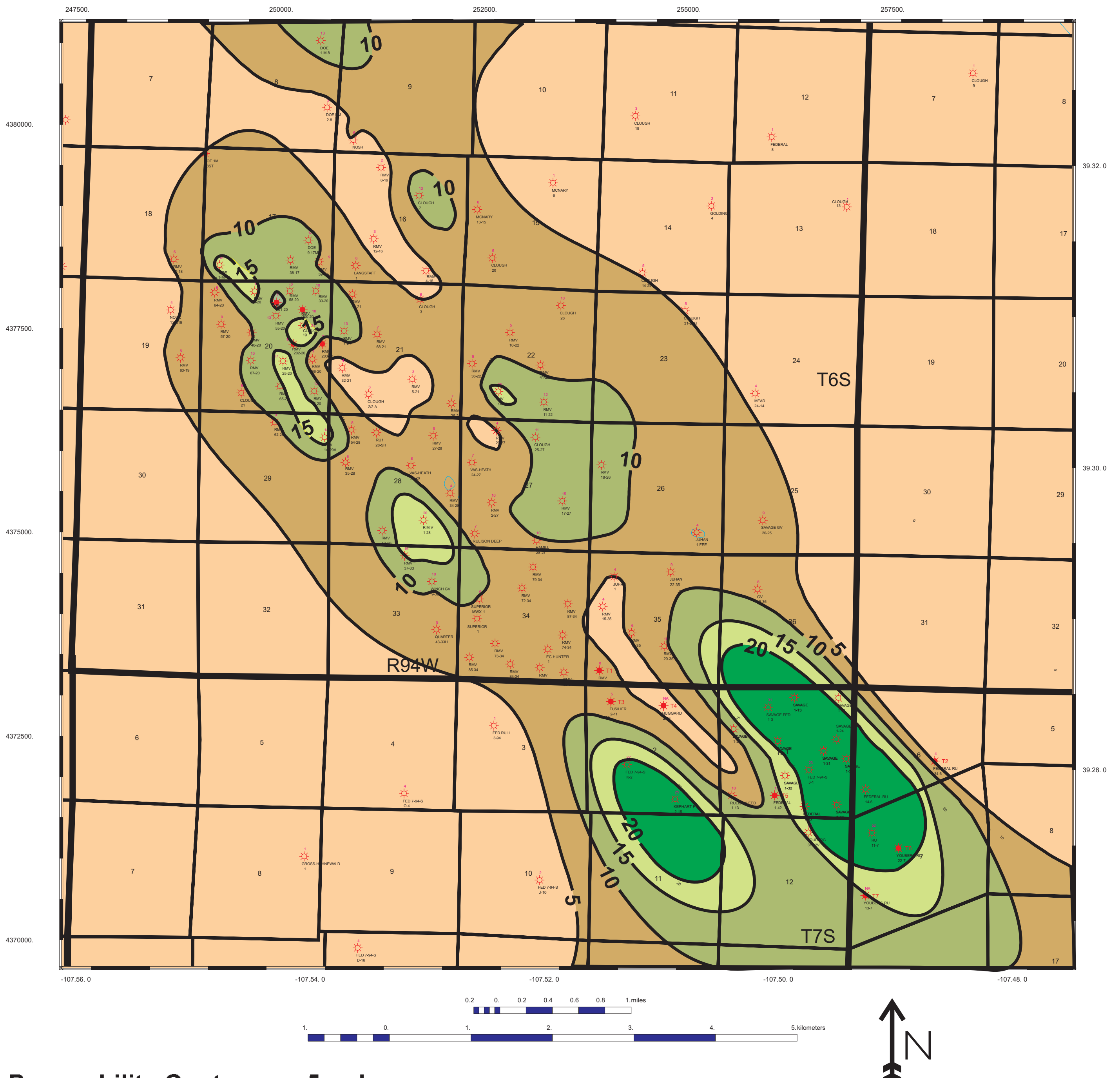
Rank	Field	Basin	State	1997 Gas Production (Bcf)
1.	Basin	San Juan	NM	787
2.	Blanco	San Juan	NM/CO	606
4.	Giddings	Austin Chalk	TX	383
5.	Carthage	East Texas	TX	212
7.	Antrim	Michigan	MI	123
9.	Bob West	Gulf Coast	TX	106
11.	Wattenberg	Denver	CO	95

The Exploration Challenge

- **Increase success by locating naturally fractured "sweet spots",** ***prior to drilling*****.**
- **Highly productive "sweet spots" occur where:**
  – ***Local natural fracture clusters overprint the regional natural fracture system.***

  – ***Local natural fracture system coincides with thick, gas-charged pay.***

Map View of Williams Fork Reservoir Permeability, Rulison Field



Permeability Contours -- 5 md

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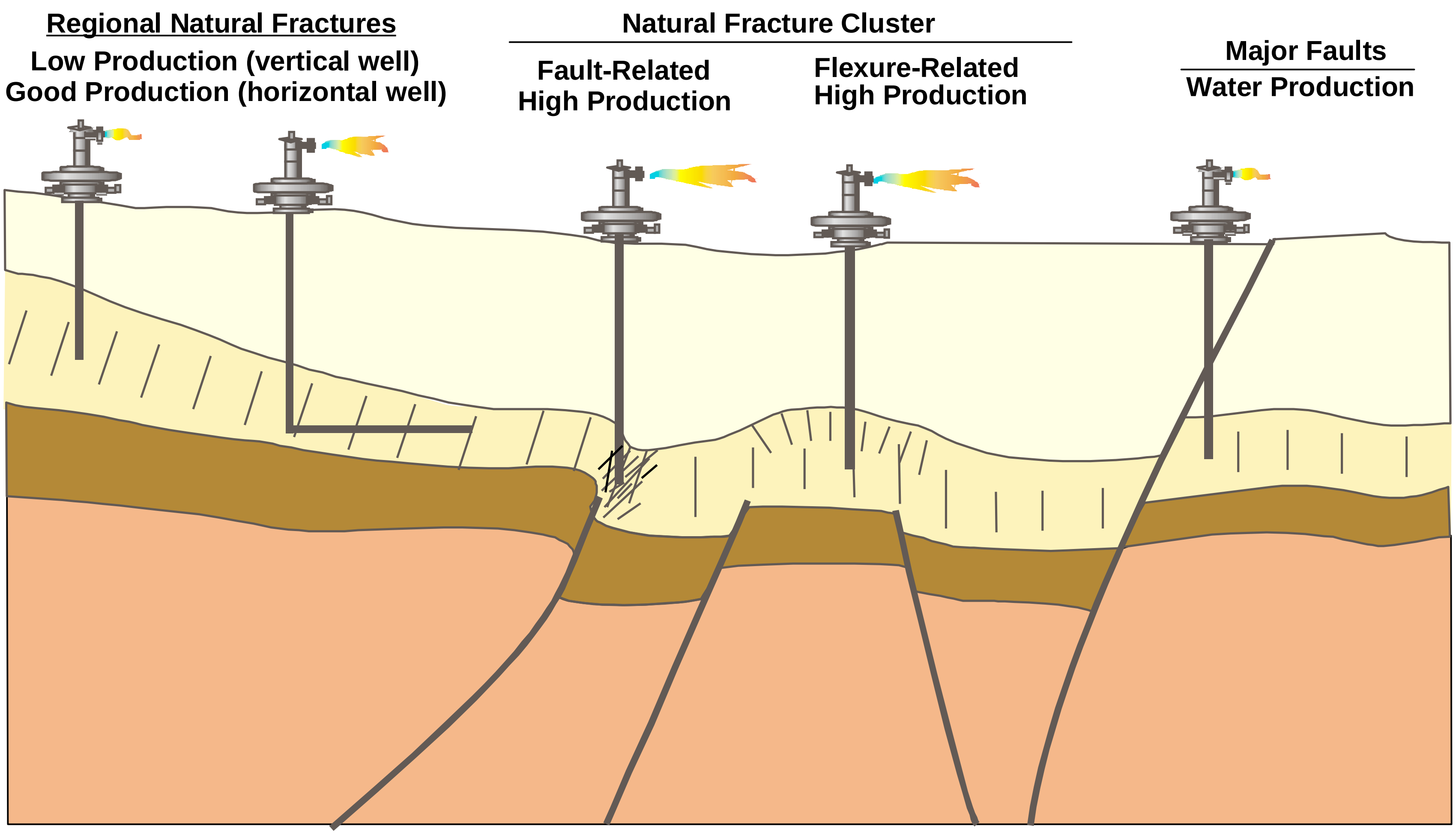
Distribution of Natural Fractures and "Sweet Spots"

- **Local, one to ten sections in size, areas of fracture enhanced permeability exist in low-permeability reservoirs.**
- **These fault-related fractured areas can be located with seismic and geomechanical methods.**
- **The randomness of well behavior in fractured reservoirs is due to sampling not fundamental geology.**

The Exploration Challenge: Finding Favorable Natural Fracture Settings



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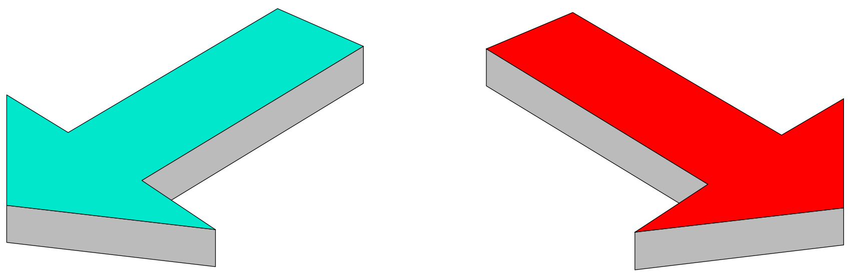
Fractured Reservoir Development Strategy

<u>Basin and Regional High-Grading</u>

Remote Sensing for Surface Features
Gravity and High Resolution Aeromagnetics
Calibration with Subsurface Data



Statistical/Step Out Approach

Prospect Definition

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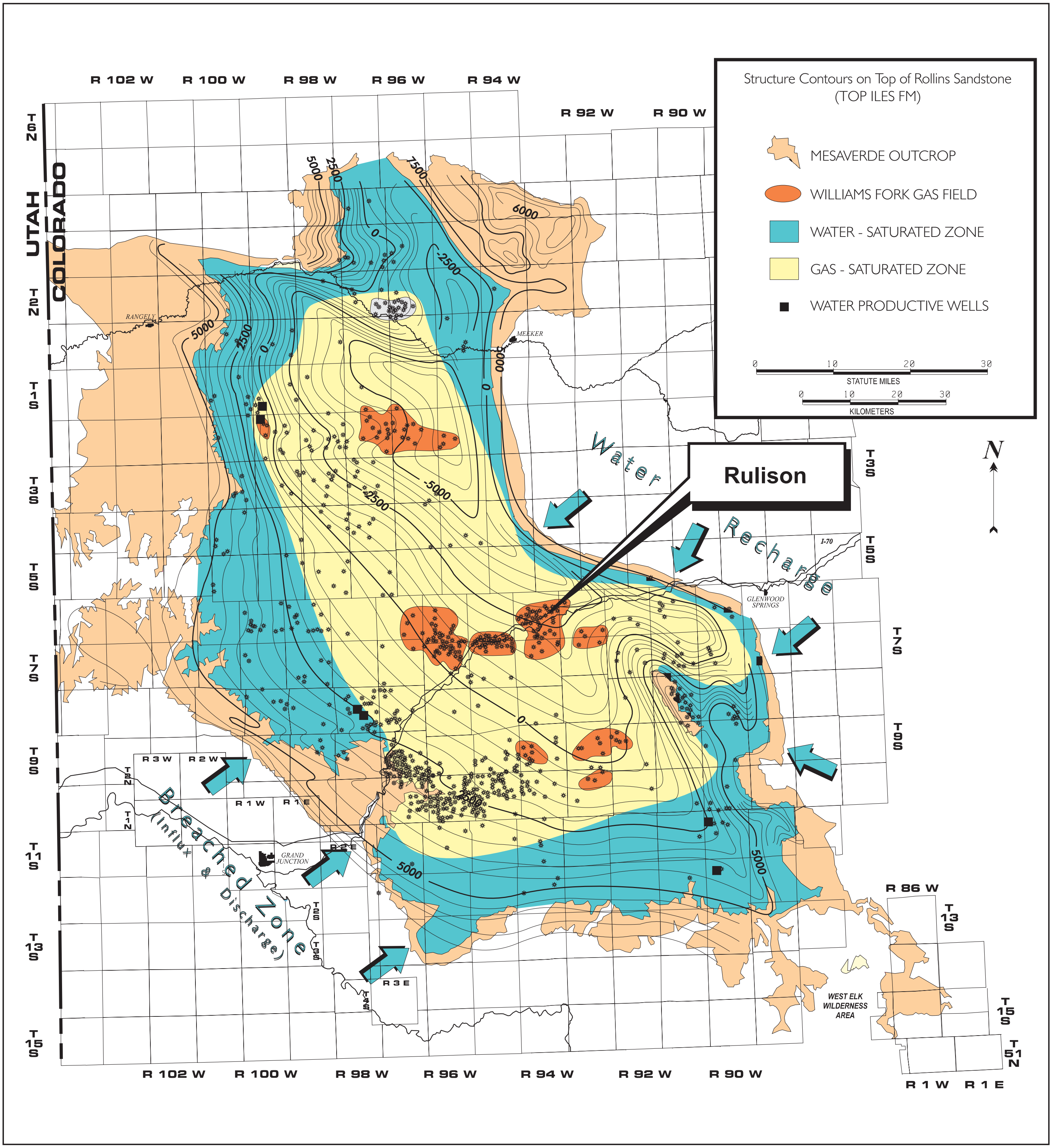
Rulison Field Case Study

Williams Fork Fm, Piceance Basin



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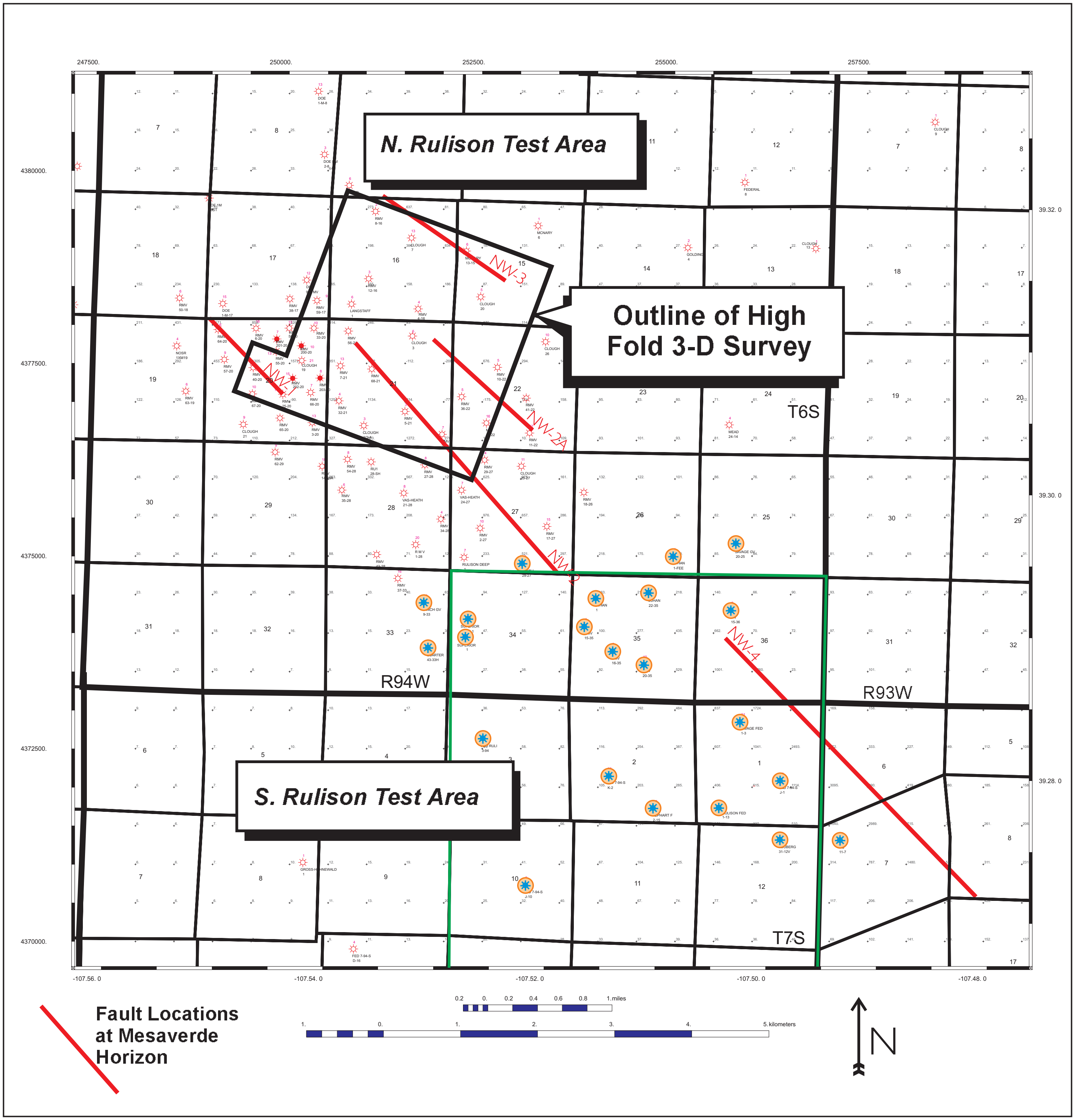
North and South Rulison Test Areas and 3-D Seismic Survey

Development Objective (in mid-'96) was to Extend the Rulison Field to the South-East



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Fractured Reservoir Development Strategy

Basin and Regional High-Grading

Remote Sensing for Surface Features
Gravity and High Resolution Aeromagnetics
Calibration with Subsurface Data

Statistical/Step Out Approach

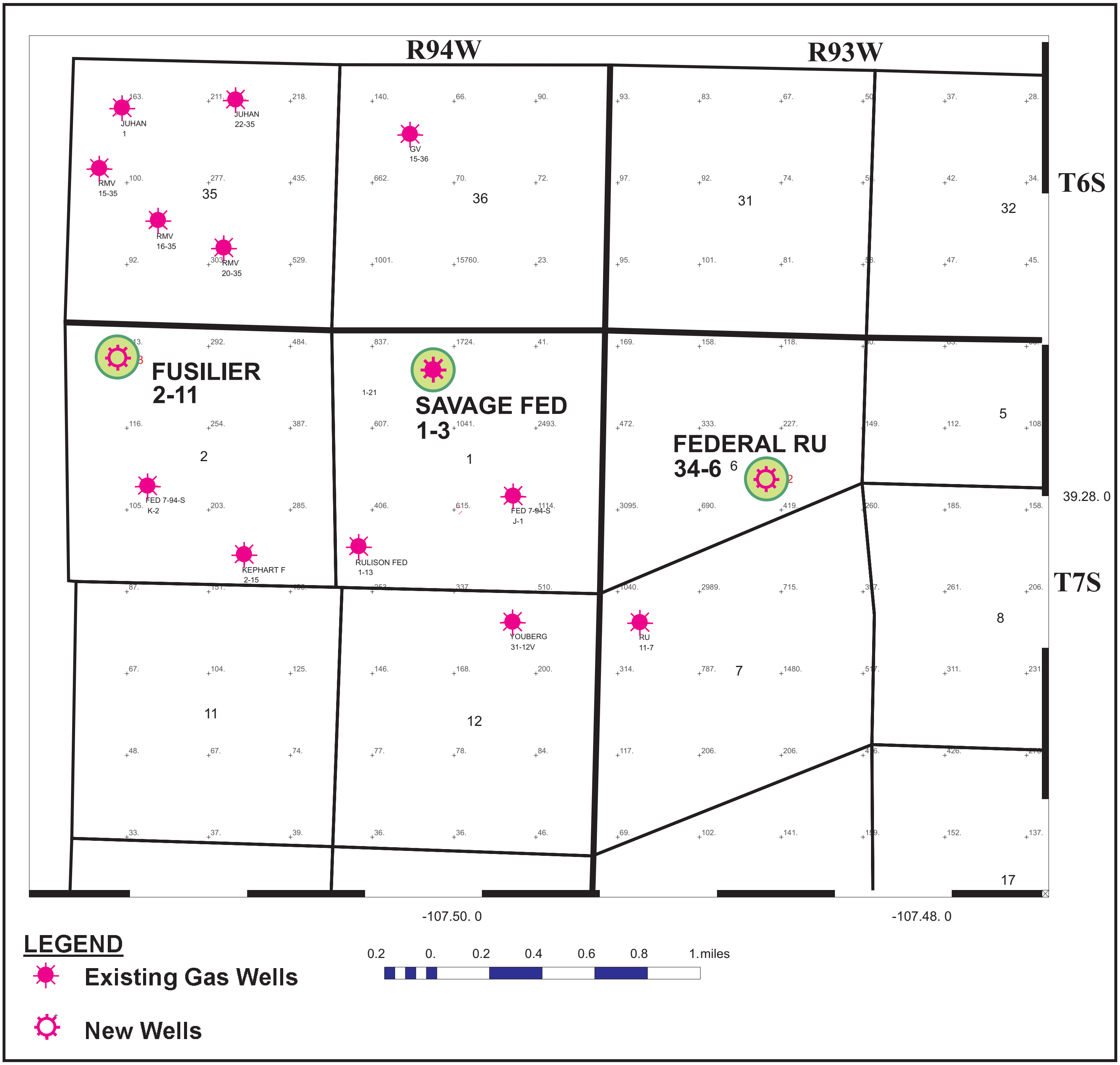
- **Multiple Well Drilling Program**

Prospect Definition

- **Seismic**
- **Geomechanical Modeling**

South Rulison Field, Piceance Basin

Dramatic Changes In Well Performance Are A Characteristic of the Williams Fork Fm



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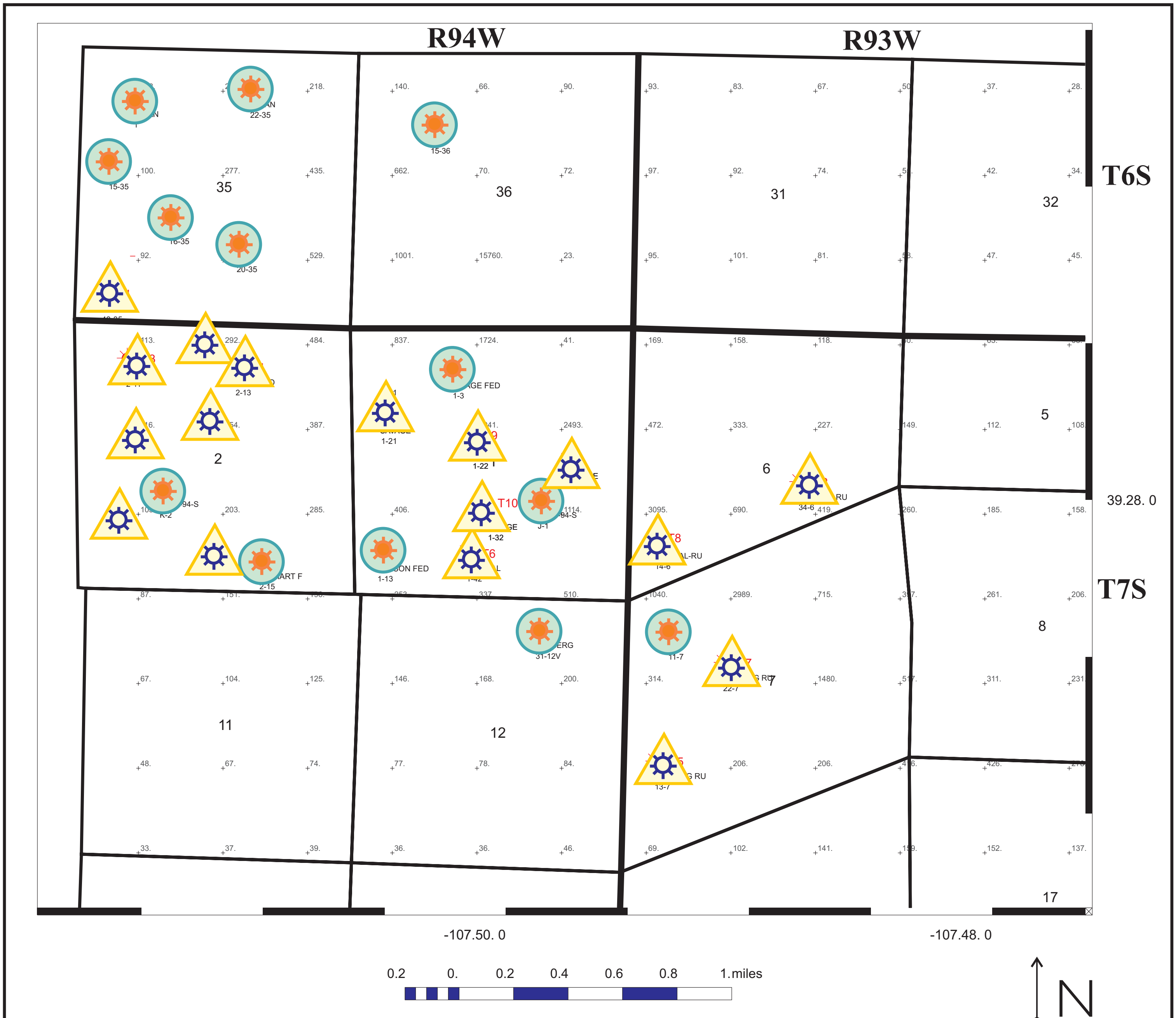
Performance of Three Closely Spaced Wells, S. Rulison Field

	Well #1 Fusilier 2-11 (Sec. 2, T7S, R94W) (Compl. 7/97)	Well #2 Savage Fed 1-3 (Sec. 1, T7S, R94W) (Compl. 2/95, Rec. 10/96)	Well #3 Federal RU 34-6 (Sec. 6, T7S, R93W) (Compl. 12/96)
EUR	0.9 Bcf	4.5 Bcf	0.3 Bcf
NET PAY	300 ft	322 ft	285 ft
Porosity	9.8%	10.60%	12.2%
Permeability	4 md	14 md	2 md

South Rulison Field, Piceance Basin

By Early '98, 35 Wells Completed Using Statistical/Step Out Drilling



Legend

Exploration/Validation Wells (17) (13 Represented)

Step Out/Delineation Wells (18) (17 Represented)

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S. Rulison: Step Out Approach

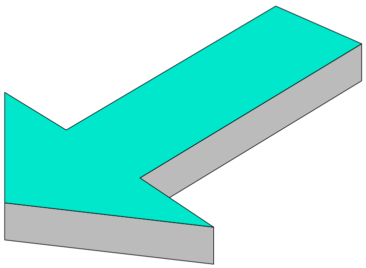
1. **Exploration and Validation**
   - ***17 wells (1990-96)***
   - ***$15.3 million****
2. **Step Out and Delineation**
   - ***18 wells (1996-Present)***
   - ***$16.2 million***
3. **Results:**
   - ***Reserves 63 Bcf***
   - ***Total Costs - $31.5 million***

**Assuming $0.9 million per well.*

Fractured Reservoir Development Strategy

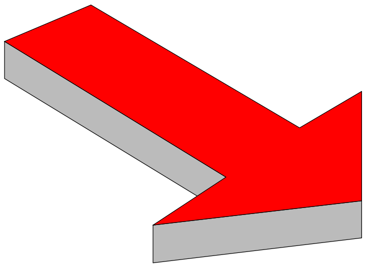
<u>Basin and Regional High-Grading</u>

Remote Sensing for Surface Features
Gravity and High Resolution Aeromagnetics
Calibration with Subsurface Data



Statistical/Step Out Approach

- **Multiple Well Drilling Program**

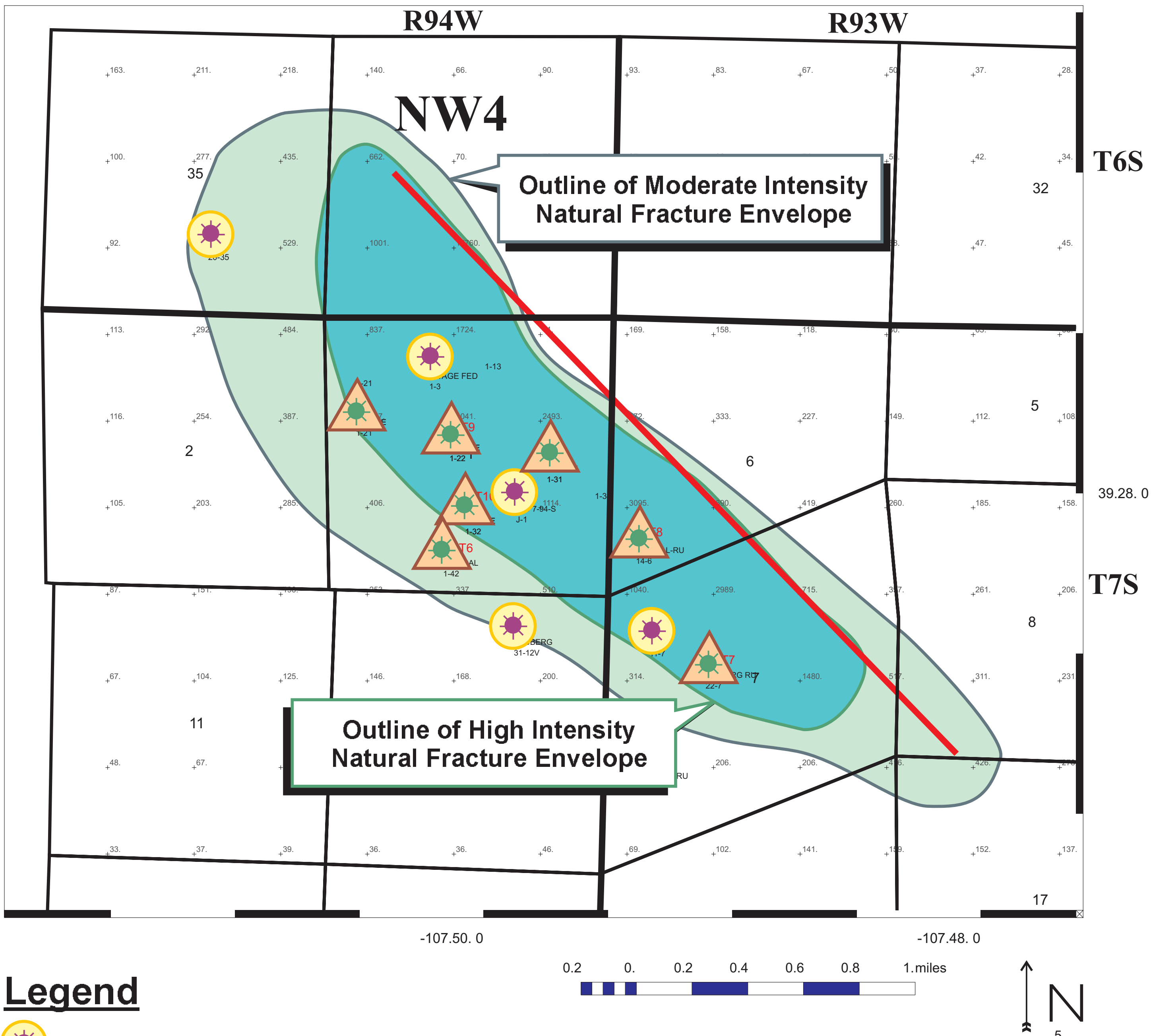


Prospect Definition

- **Seismic**
- **Geomechanical Modeling**

South Rulison Field, Piceance Basin

Alternative is Using Prospect Definition (Seismic and Geomechanics) to Locate Wells in Naturally Fractured "Sweet Spots"



Legend

Exploration/Validation Wells (5)

Step Out/Delineation Wells (7)

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S. Rulison: Prospect Definition Approach

1. **Exploration and Validation**
   - ***72 square miles 3-D seismic, plus geomechanical analysis***
   - ***5 wells***
   - ***$6.6 million****

2. **Step Out and Delineation**
   - ***7 wells***
   - ***$6.3 million***

3. **Results:**
   - ***Reserves 40 Bcf***
   - ***Total Costs - $12.9 million***

**Assuming $1.8 million for seismic survey, $0.3 million for analysis, $0.9 million per well.*

Comparison of Step Out Approach vs. Prospect Definition

	Step Out Approach	Prospect Definition
• Costs*	$31.5 MM	$12.9 MM
• Reserves	63 Bcf	40 Bcf
• Wells	35	12
• Reserves/Well	1.8 Bcf	3.4 Bcf
• Finding Costs @85% NRI	$0.59/Mcf	$0.38/Mcf

**Includes $0.9 million per well and $2.1 million for seismic and geomechanical analysis.*

Cost Savings From Using Prospect Definition (Seismic and Geomechanics) for Efficient Field Development
(S. Rulison Example)

	Statistical/ Step Out Approach	Prospect Definition
Target Reserves	1,000 Bcf	1,000 Bcf
Average EUR/Well	1.8 Bcf*	3.4 Bcf**
No. of Wells	556	294
Capital Costs*** (@$900,000/well)	$500 million	$267 million
Cost Savings		**$233 million**

****Average EUR for 35 wells statistically drilled in S. Rulison area.***

*****Average EUR for 12 wells located and drilled in naturally fractured envelope***

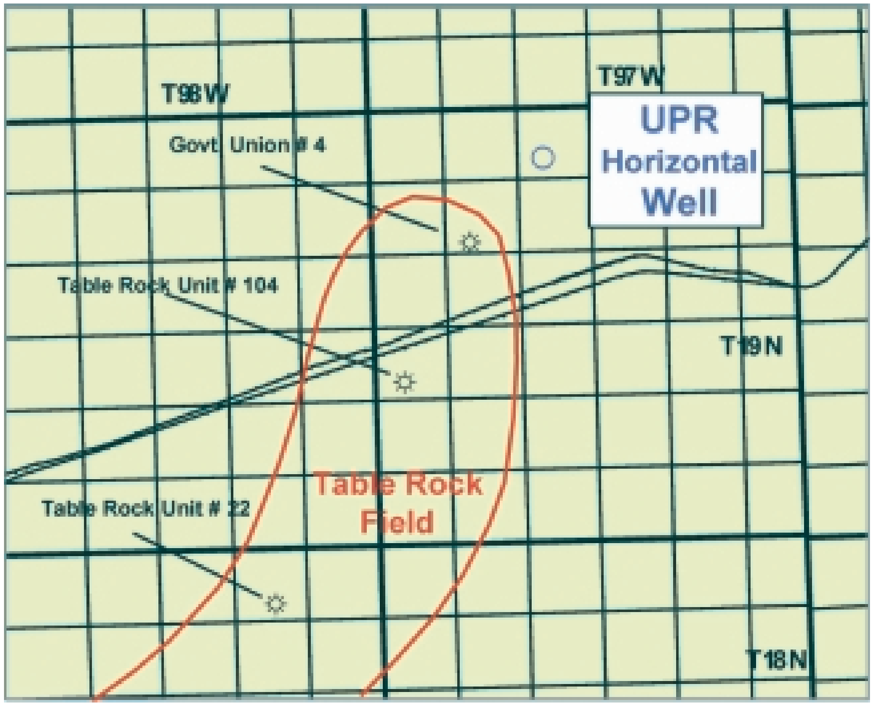
******Capital costs of Prospect Definition include $2.1 million for seismic and geomechanical analysis.***

Table Rock Field Case Study
Frontier Fm., Green River Basin

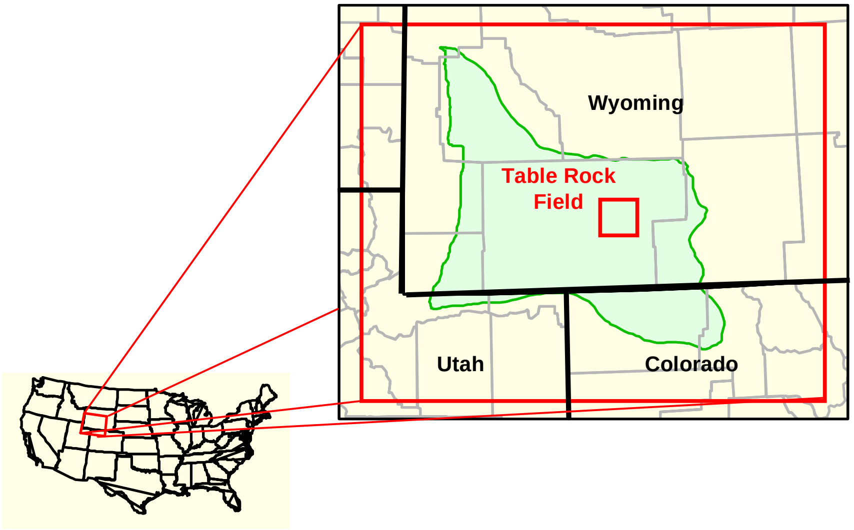
<u>Deep, High Risk Frontier Fm. Reservoir</u>

- ***15,000'; 270º F; 10,000 psi***
- ***Unsuccessful exploration well at Frewen***
- ***World record tight gas horizontal well***

Table Rock Field



Greater Green River Basin



Prospect Corroboration

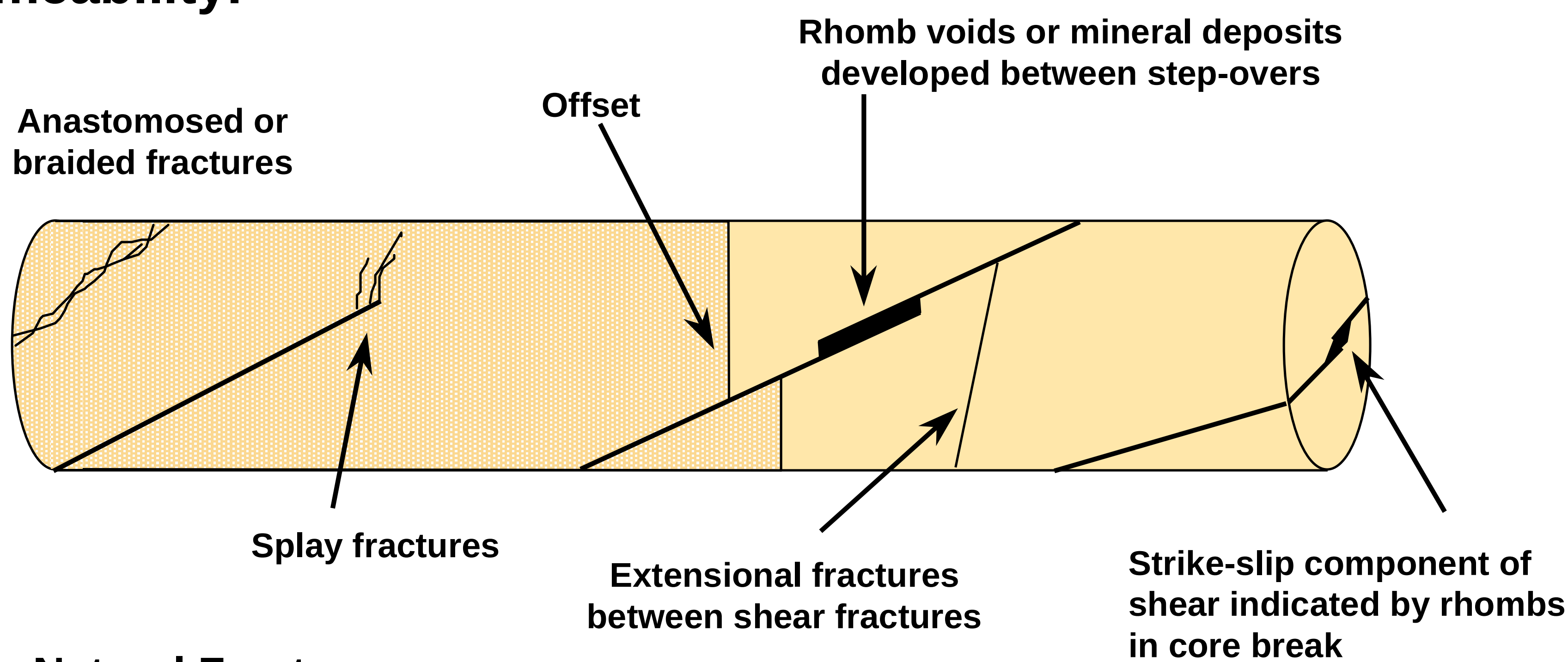
Given expense and risk of horizontal drilling, statistical approach to locating exploration wells in deep, high-risk Frontier Fm is not viable.

ARI's role was to corroborate the horizontal well location using the Prospect Definition approach:

- ***Natural Fracture Characterization***
- ***Fault Mapping Using 3-D Seismic***
- ***Geomechanical Modeling***

Natural Fracture Characterization: Table Rock, Green River Basin

- **Natural fractures in Frontier Fm are dominantly oblique-reverse shears with extensional component.**
- **Open voids provide storage; <u>shear fractures</u> provide permeability.**

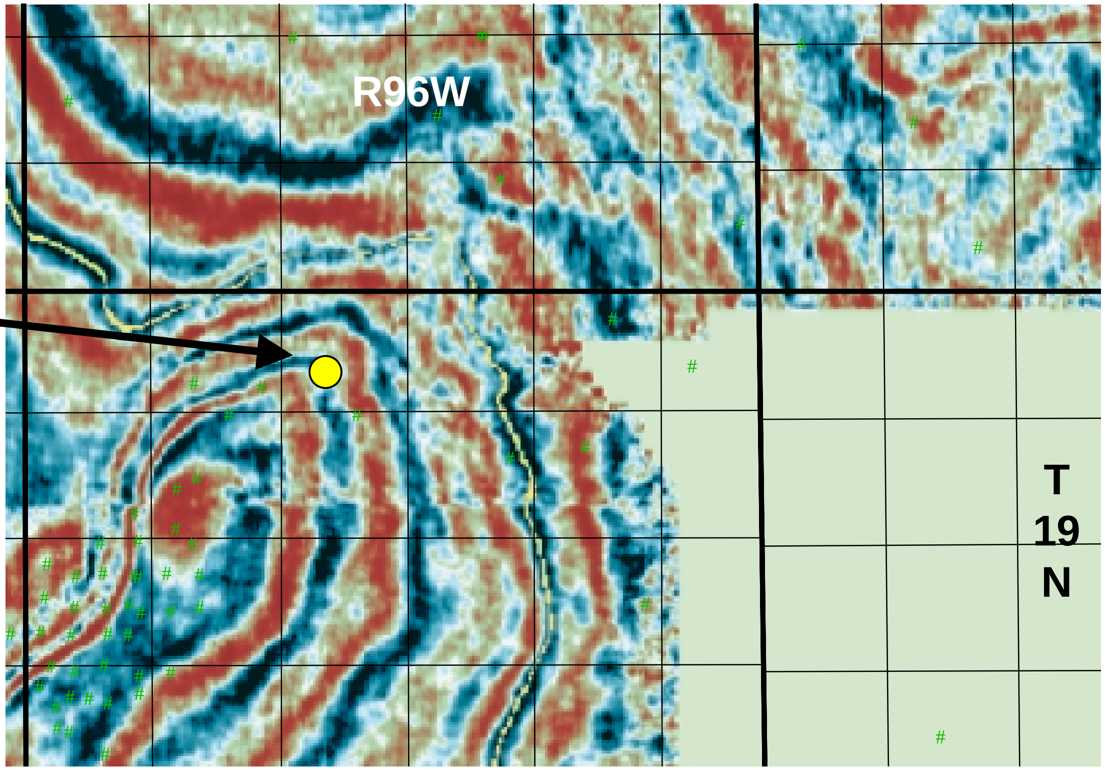


Natural Fractures Observed in Core

3D Seismic: Depth Slice 16,000’

Location of Rock Island 4H is on the northern nose of the Table Rock fold (off-structure).

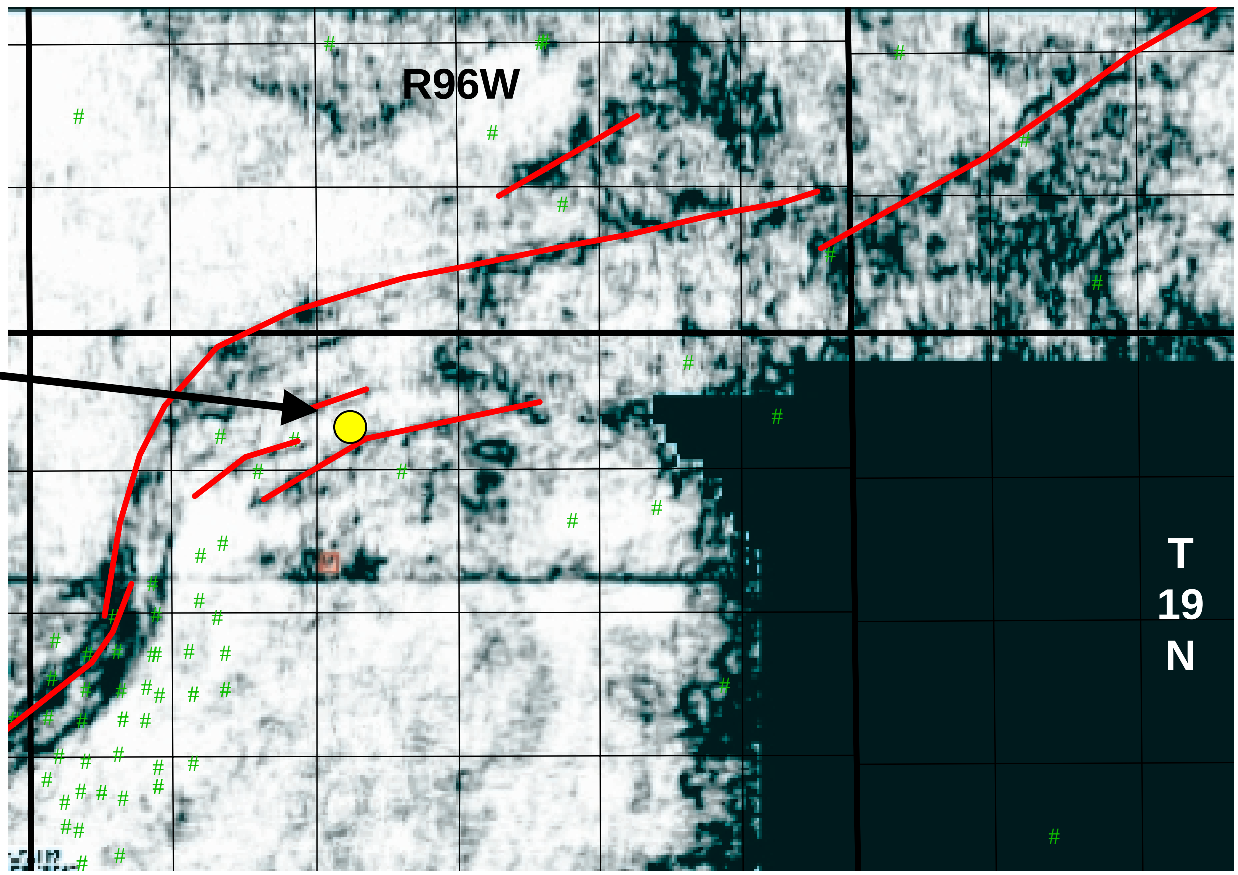
Rock
Island
4H



3D Seismic: Fault Mapping

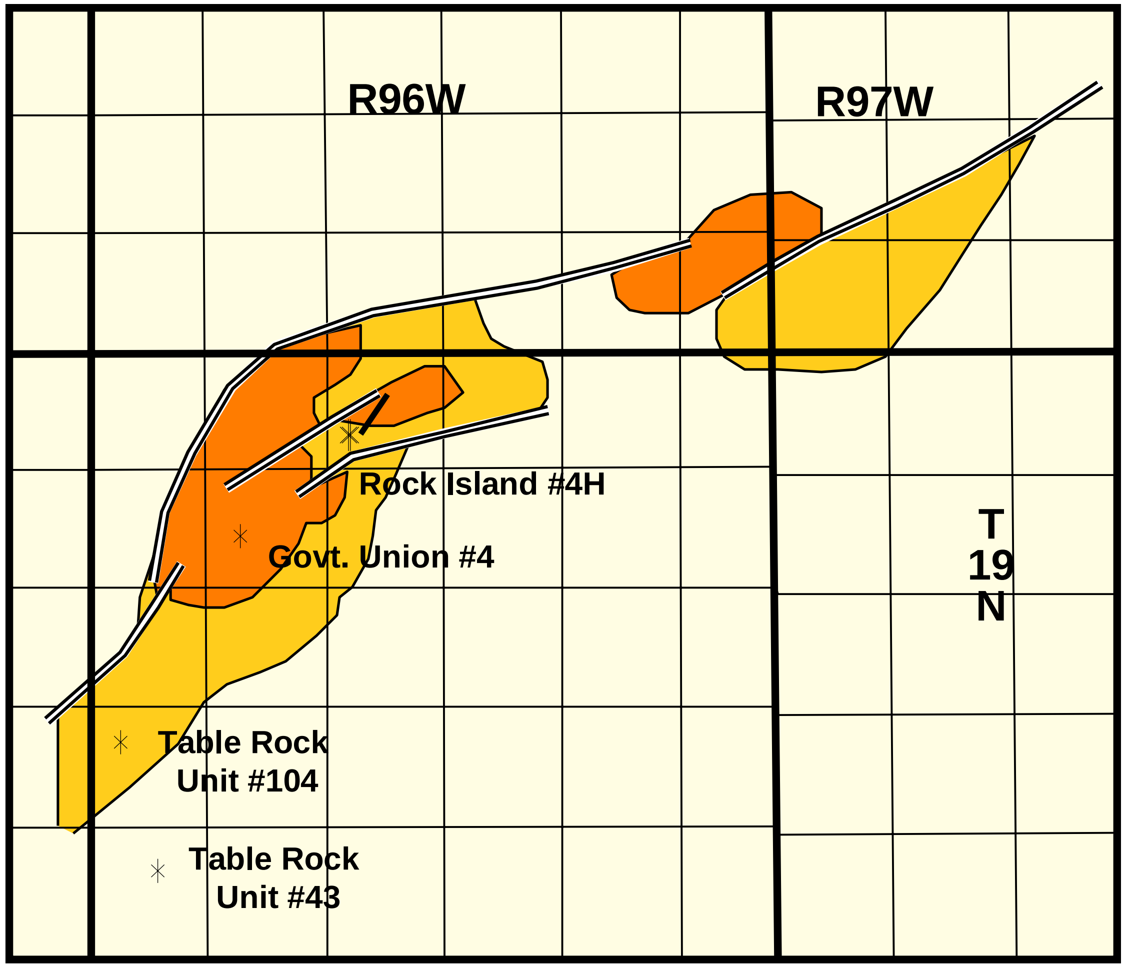
Subtle faults and complex geometry of the main thrust and strike-slip fault system are revealed after coherency filtering.

Rock Island 4H



Natural Fracture Prediction: Geomechanical Model Results

The Rock Island 4H occupies an area between two small faults and may have hit a zone of enhanced stress concentration.



Prospect Definition Results

Monday April 26, 10:55 am Eastern Time

UPR'S HORIZONTAL WELL TESTED
AT OVER 12 MMCFD

Union Pacific Resources Group, Inc., Working with Federal Energy Tech Center, Completes Experimental Horizontal Frontier Formation Gas Well

Value of Using Seismic and Geomechanics for Prospect Definition

1. **Play Assessment. Provides viable leads for an economic tight gas exploration program.**

2. **Exploration Success. Helps avoid "program killers", early dry holes.**

3. **Efficient Development. Provides a low cost approach for developing low-permeability gas fields.**

Summary

1. ***Tight Gas, Gas Shales and Coalbed Methane Can Provide Large, Economic Resource Targets.***

2. ***Prospect Definition, Using the Geomechanical Approach to Natural Fracture Prediction, Is a Cost-Effective Alternative to Step Out and Statistical Drilling.***

Summary

3. ***The Geomechanical Approach Provides a Low Cost, Advanced Exploration Tool for Naturally Fractured Reservoirs:***
   - ***2D and 3D seismic data***
   - ***Standard seismic processing***
   - ***Available numerical simulator***

4. ***Successful Results Have Been Achieved at Rulison (and Mamm Creek), Piceance Basin and Table Rock, Green River Basin.***